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Long T. Phan, Nicholas J. Carino, Dat Duthinh, and Edward Garboczi



B.9 Mechanical Properties of Siliceous HSC Subjected to High-Temperature Cycles

R. Felicetti and P.G. Gambarova

Department of Structural Engineering, Milan University of Technology, Milan, Italy

Highly-stressed structural members rely more and more on high-strength concretes and -- in certain specific cases -- on very high-strength microconcretes, which are quite sensitive to severe thermal loading (high temperature), particularly when highly-siliceous aggregates are used. As part of a joint Research Project financed by the European Communities, a number of industrial partners and research institutions (like the Italian National Agency for Energy, New Technologies and Environment - ENEA), a many-faceted research program in the domain of siliceous high-strength concretes ($f_c = 72\text{-}95$ MPa) and special microconcretes (Reactive Powder Concretes and Compact Reinforced Concretes, $f_c = 170\text{-}200$ MPa) is in progress in Milan. The objectives of the project regard the measurement of the complete stress-strain curves in compression and in tension both at room temperature and after or during a cycle at high temperature ($T = 105\text{-}500^\circ\text{C}$), and the evaluation of a few fracture parameters (fracture energy, characteristic length, toughness index), as a function of the temperature of the thermal cycle. Both the material and the structural behavior are investigated, since the thermally-induced softer behavior of the concrete favors stress redistribution in a structure, making the overall structural behavior less sensitive to high temperature than the material itself.

The research project in progress at Milan University of Technology consists of 4 different phases:

- Compression and tension strength of flint-based, high-strength concretes: residual properties are measured after a cycle at 105, 250, 400 and 500°C (heating and cooling in quasi-steady conditions, with 12 hours at the maximum temperature) [1, 2], Figs. 1 and 2; notched (tension) and unnotched (compression) cylinders ($f_c = 72$ and 95 MPa) are used.
- Deep beams subjected to 3-point bending and circular slabs subjected to punching (both reinforced and unreinforced): residual capacity is measured (load-displacement behavior included) after a thermal cycle at 105, 250 and 400°C (flint-based concrete with $f_c = 72$ MPa); deep beams and circular slabs are typical structural elements in plane stresses and subjected to shear and bending [2, 3], Figs. 3 and 4.
- Tension behavior of flint based high-strength concretes ($f_c = 72$ and 95 MPa): evaluation of the fracture energy per unit volume in the case of multiple or distributed cracking (PIED prisms, for evaluating the damage density in tension [4], Fig. 5, and the characteristic length), after a cycle at high-temperature ($T = 105\text{-}400^\circ\text{C}$). The unnotched specimens are loaded by means of steel or aluminium rods, which are glued to the lateral surface.

- Tension behavior of one high-strength calcareous concrete ($f_c = 95$ MPa) and of two very high-strength fiber-reinforced microconcretes (RPC and CRC): the stress-strain and stress-crack opening curves will be measured at high temperature ($T = 105-400^\circ\text{C}$). Special dumbbell-shaped and notched specimens (Fig. 6) have been cast in order to make it possible to extract the measures from the specimens loaded inside the furnace. The specimens are provided with special threaded ends, which permit their attachment to the press platens. The tests will be displacement-controlled, as in all previous cases. This phase of the project is being carried out in close collaboration with Prof. Gabriel A. Khoury of London, taking advantage of the test facilities for high temperatures which are available at the Department of Civil Engineering at the Imperial College. Further tests regarding the residual behavior after the thermal cycle will be carried out in Milan, as well as most of the data processing.

Phases 1 and 2 are completed, while Phase 3 is well advanced and Phase 4 is in the initial stage, but all the measurements should be available and processed by October 31, 1997.

The results of phases 1 and 2 show clearly that the residual mechanical properties of highly siliceous concretes are dramatically affected by a long exposure to high temperature, both in compression and in tension, while the structural behavior is less affected, since the material becomes softer and the sensitivity to high temperature of the reinforcement, if any, is quite limited ($T \leq 500^\circ\text{C}$).

As for distributed damage with multiple cracking (Phase 3), the softening branch of the stress-strain response is definitely less steep than with crack localization, and tends to flatten-off after exposure to very high temperature. At the same time the characteristic length tends to increase with the temperature.

- [1] Felicetti R. and Gambarova P.G. (1996), "*On the residual mechanical properties of siliceous high-strength concretes subjected to a high temperature cycle*", Special Volume on the Occasion of Professor Mehlhorn's Retirement, Kassel University, Kassel (Germany), in press.
- [2] Felicetti R., Gambarova P.G., Rosati G., Corsi F. and Giannuzzi G., (1996) "*Residual Mechanical Properties of High Strength Concretes Subjected to High Temperature Cycles*", Fourth International Symposium on Utilization of High Strength/High Performance Concrete, Paris, Vol. 2, pp. 579-588.
- [3] Felicetti R. and Gambarova P.G., "*HSC deep beams and slabs damaged by high temperatures*", ASCE - 1996 Annual Convention, Washington D.C., November 10-14, 1996, pp. 583-592.
- [4] Di Prisco, M. and Mazars, J. (1996), "*Crush-crack: a non-local damage model for concrete*," Mechanics of Cohesive-Frictional Materials and Structures, Vol. 1, pp. 321-347.

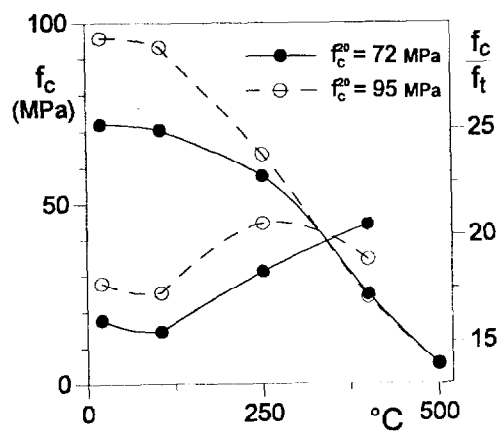


Figure 1

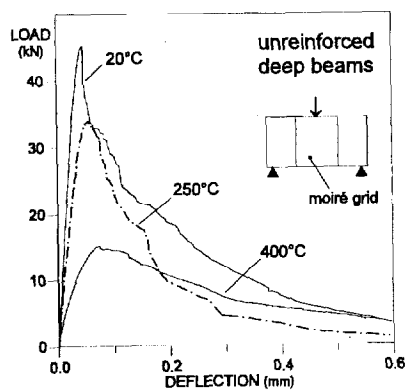


Figure 2

Figure 3

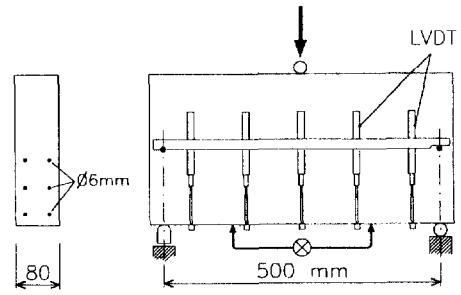


Figure 4

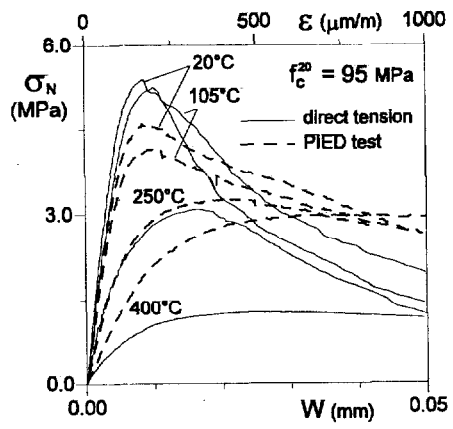
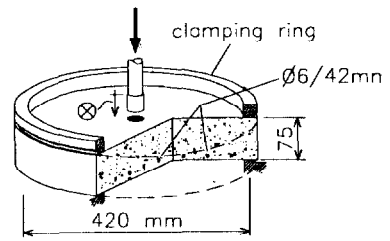


Figure 5

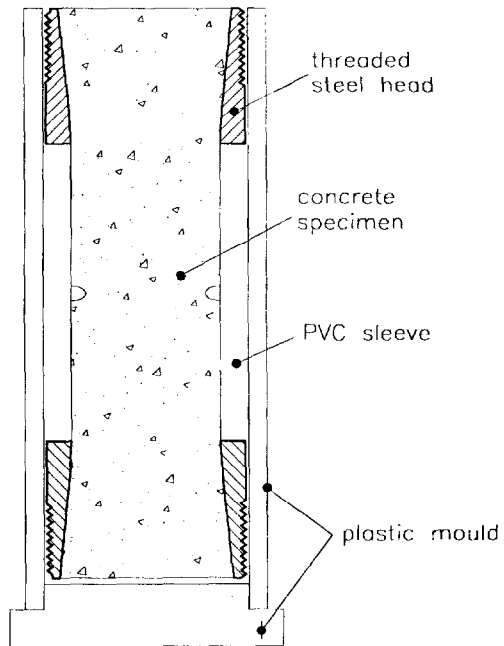


Figure 6